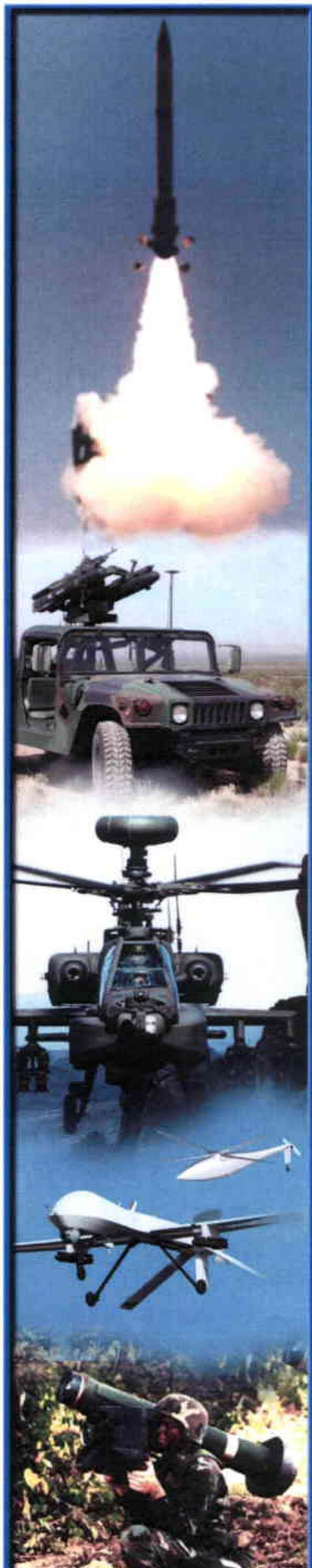

TECHNICAL REPORT RDMR-WD-10-39

Character Animation Technologies for the Common Driver Trainer (CDT)

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13. ABSTRACT *(Maximum 200 Words)*

The U.S. Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) was tasked to analyze options for character animation improvement in the Common Driver Trainer (CDT). This report provides a discussion of some of the available technologies and shows that since the CDT is currently required to use one specific vendor for the Image Generator (IG), the only good option for character animation is Boston Dynamics DI-Guy. This is due to the fact that the IG is already integrated with DI-Guy. Considering the likely cost of changing the IG to use another character animation technology, even one that is government-owned, AMRDEC recommended that the CDT program obtain the necessary licenses to DI-Guy for integration with the trainer. However, it was also recommended that the CDT program remove the requirement for a specific IG, allowing other commercial, open source, or government-owned rendering capabilities to be considered in the future, thus opening the door for other character animation technologies.

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EXECUTIVE SUMMARY

The Common Driver Trainer (CDT) program is in need of an improved capability for character animation. The US Army Aviation and Missile Research, Development, and Engineering Center (AMRDEC) is providing support to the CDT program and was tasked to analyze options for the CDT character animation improvement. This report provides a discussion of some of the available technologies. However, while the long-term goals of the program may allow more flexibility in the rendering engine and thus the character animation capability, the CDT is currently required to use one specific vendor for the Image Generator (IG). This requirement limits the options available for character animation to that which is currently supported by the IG or requires the vendor to make changes to the IG directly. The only good option currently integrated with the IG is Boston Dynamics DI-Guy. Considering the likely cost of changing the IG, along with the fact that the DI-Guy solution will meet the most critical near-term requirements, AMRDEC recommends that the CDT program obtain the necessary licenses to DI-Guy for integration with the trainer. However, it is also recommended that the CDT program remove the requirement for a specific IG, allowing other commercial, open source, or government-owned rendering capabilities to be considered in the future, thus opening the door for other character animation technologies.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

While limited character animation is currently available in the Common Driver Trainer (CDT), a requirement was provided by the Program Executive Office for Simulation, Training, and Instrumentation (PEO STRI) to improve this capability. The Aviation and Missile Research, Development, and Engineering Center (AMRDEC) was tasked to research the available options for improving the character animation in the CDT. The results of this research are documented in this report, along with a recommended path forward.

II. COMMON DRIVER TRAINER OVERVIEW

The CDT provides both initial and sustainment training for several families of vehicles, including the Stryker, Abrams, and Mine Resistant Ambush Protected (MRAP) vehicles. The components of the CDT (Fig. 1) include the vehicle cab, the visual system, the Instructor/Operator Station (IOS), the After Action Review (AAR) station, the motion system, and various computers for the simulation and image generation[1].

The vehicle cab is interchangeable between the various platforms supported by the CDT. This ensures commonality among many of the components for the various vehicle types supported. The display system is controlled by a commercial Image Generator (IG), specifically the Rockwell Collins EPX-50. The EPX-50 uses Commercial Off-The-Shelf (COTS) Personal Computers (PCs) and is currently listed as the required IG for the CDT. The host simulation computer communicates to the EPX IG using the Common Image Generator Interface (CIGI) standard.

The IOS utilizes another IG in the EPX family, the EPX-5, which provides EPX features on a single COTS PC. The IOS allows the instructor to select the scenario for the student to execute and to monitor the student's progress during the exercise. Additionally, the instructor can provide verbal instructions to the student through the intercom system and insert system faults. Finally, the IOS supports recorded AAR for reviewing the student's performance.

There are several reasons to include character animation in the CDT simulation. Most importantly, part of the training requires the student to follow an animated human character, or ground guide, including responding appropriately to hand-and-arm signals. Also, there is necessity to include a certain degree of pedestrian traffic to contribute to the realism of the training scenarios. While both of these capabilities are available to some degree in the current version of the CDT, those features do need to be improved. A degree of crowd modeling technology should also be added to assist in placing realistic quantities of humans quicker in a scenario. Finally, the character animation is not limited entirely to human modeling, but it must also include models of animals that can be given animated behaviors.

Figure 1. Common Driver Trainer Stryker Variant[1]

III. SPECIFIC CDT REQUIREMENTS

There are numerous character animation requirements that have been placed on the CDT program. Some of these requirements are listed below.

A. Scenario Generation System Specific Requirements[2]

Section A-3.7.2.4.5, Humans

The CDT scenario generation system shall allow the Scenario Author to set the overall human density, movement parameters and behavior (i.e. friendly, angry) for SAF controlled humans for the scenario.

The CDT scenario generation system shall allow the Scenario Author to select individual Humans from a pull-down menu and place them in the scenario.

The CDT scenario generation system shall allow the Scenario Author to place humans at any realistic location within the terrain database including on rooftops and in windows.

The CDT scenario generation system shall allow a Scenario Author to equip CM2 human models with human portable weapons.

The CDT scenario generation system shall allow a Scenario Author to assign behaviors to CM2 human models.

The CDT scenario generation system shall allow a Scenario Author to associate scripted events with CM2 human models.

The CDT scenario generation system shall allow the Scenario Author to select normal, wounded or killed state for each CM2 human model placed in a scenario.

The CDT scenario generation system shall allow the Scenario Author to place CM2 human models which have a killed state lying in any orientation on the ground.

CM2 human models which have a killed state shall not be capable of movement.

The CDT scenario generation system shall include a library of human models capable of performing the hand and arm actions of mounted and dismounted ground guides. The CDT scenario generation system ground guide models shall include both day and night models. The CDT scenario generation system shall allow a Scenario Author to select ground guide models from a pull-down menu and place them in a scenario. The CDT scenario generation system shall allow a Scenario Author to place an Activation Point along an ownvehicle path or to set an Activation Time to activate the ground guide behavior for the ground guide model.

The CDT SAF software shall include ground guide behaviors capable of guiding a human controlled ownvehicle:

- Out of a parking space in a row of vehicles (driving forward)
- Along a scripted path (driving both forward and reverse)
- Through a maintenance bay in a building (driving forward)
- Onto a HET trailer (driving forward)
- Off a HET trailer (driving forward)
- Onto a railroad car (driving forward)
- Off a railroad car (driving forward)
- Onto a ship (driving forward)
- Off a ship (driving forward)
- Onto an aircraft (driving forward)
- Off an aircraft (driving forward)
- Into a parking space (driving forward or reverse)
- Into various military formations (mounted ground guide only)

Section A-3.7.2.4.5, Animals

The CDT scenario generation system shall allow the Scenario Author to set the overall animal density, movement parameters and behavior (i.e. stationary, wandering) for SAF controlled entities for the scenario.

The CDT scenario generation system shall allow the Scenario Author to select Animals from a pull-down menu and place them at any realistic location within the terrain database in the scenario.

The CDT scenario generation system shall allow the Scenario Author to select normal or killed state for each CM2 animal model placed in a scenario.

The CDT scenario generation system shall allow the Scenario Author to place CM2 animal models which have a killed state lying in any orientation on the ground.

CM2 animal models which have a killed state shall not be capable of movement.

B. CDT Common SRD Requirements[3]

Section 3.2.1.3.4.16, Interactive Human Model

A host controlled, animated, interactive human model shall be provided that gives visual hand and arm signals to direct vehicle movement or vehicle equipment configuration. The animated, interactive human model shall have the capability of executing a minimum of 30 animated, smooth, human like, realistic hand and arm signals that correspond to real-world directions when performing vehicle maneuvering or configuration tasks. Interactive human model positioning relative to the vehicle and signals being executed shall be associated with the vehicle being simulated. The signals shall include both day and night (military flashlight in hand) military hand and arm signals.

The interactive human model signals shall be interactively controlled by evaluating the simulated vehicle's movement and position relative to a pre-defined desired path and the position relative to the interactive human model. The pre-defined path that the vehicle is supposed to follow shall have a tolerance depending on the location of the vehicle in the database. In areas that have other objects such as a motor pool stall openings, a row of vehicles, a tight passage between objects, etc., the actual vehicle location compared to the pre-defined path shall have a small tolerance. In less dense, open areas, the deviation of the vehicle from the pre-defined path shall have a larger tolerance. The interactive human model to vehicle positioning shall be evaluated for distance and offset (position in the field of view). Parameters for distance and offset shall be configurable for the vehicle being simulated. The frequency of interactive human model halts and repositions shall be minimized in order to maintain realistic progress for vehicle movements. When the simulated vehicle moves outside the acceptable tolerance or the interactive human model is outside the acceptable field of view, the interactive human model shall halt the movement and refer the student to the instructor. The interactive human model movement animations such as walking and turning shall be realistic. The interactive human model path shall not go through any database object. When directing a vehicle to back up, the front (visible) interactive human model shall act as if receiving signals from a second, rear ground guide. The simulated interactive human model shall conduct safe, procedurally correct actions.

For vehicle configuration tasks, the interactive human model shall be correctly positioned in front of the vehicle and shall provide hand and arm signal configuration commands consistent with the vehicle, vehicle equipment and equipment status. The signals shall include both day and night (military flashlight in hand) vehicle configuration hand and arm signals. When multiple steps are required for equipment configuration, the interactive human model shall provide commands only when prerequisite actions have been accomplished.

For convoy commands, the animated human model shall portray a lead vehicle commander, typically from the waist up in the lead vehicle hatch. The lead vehicle commander shall be able to give hand signal to vehicles following the lead vehicle. The lead vehicle commander's hand signals or mounted signals shall be in response to scenario requirements and triggered at specific points on the lead vehicle path.

C. Specific Requirements

Numerous requirements are provided in Sections 3.2.28 and A-3.2.3.8 of the M1A1 SA/M1A2 SEP V2 Abrams Tank Variant requirements document[4]. This document contains specific figures and descriptions that describe various hand and arm signals for the ground guide. An example figure is shown in Figure 2.

Figure 2. Sample CDT Ground Guide Animation[4]

IV. REVIEWS OF CHARACTER ANIMATION OPTIONS

A. Night Vision Animation Library (NVAL)

NVAL is a government-owned product available from the U.S. Army Research, Development and Engineering Command (RDECOM) Communications-Electronics Research, Development, and Engineering Center (CERDEC) Night Vision and Electronics Sensors Directorate located at Fort Belvoir, Virginia. The NVAL character animation system is integrated with the Night Vision Image Generator (NVIG) visualization software, which is also government-owned. However, NVAL can also be distributed as a separate library; so it does not require the use of NVIG.

The NVIG family of software tools, including NVAL, has been successfully tested for compatibility with the Windows, Red Hat Linux, and CentOS operating systems. NVAL comes with a suite of human characters which can be given various accessories, such as weapons or tools.

The biggest advantage to using NVAL on the CDT program is the fact that it is a government-owned product. Thus, there would never be a licensing fee associated with using the product, no matter how many training devices are fielded. However, the product has not been integrated with the EPX IG, so there would be development required by the vendor of that product to integrate with the NVAL software. Figure 3 shows a brochure of the NVIG, including some of the characters available with NVAL.

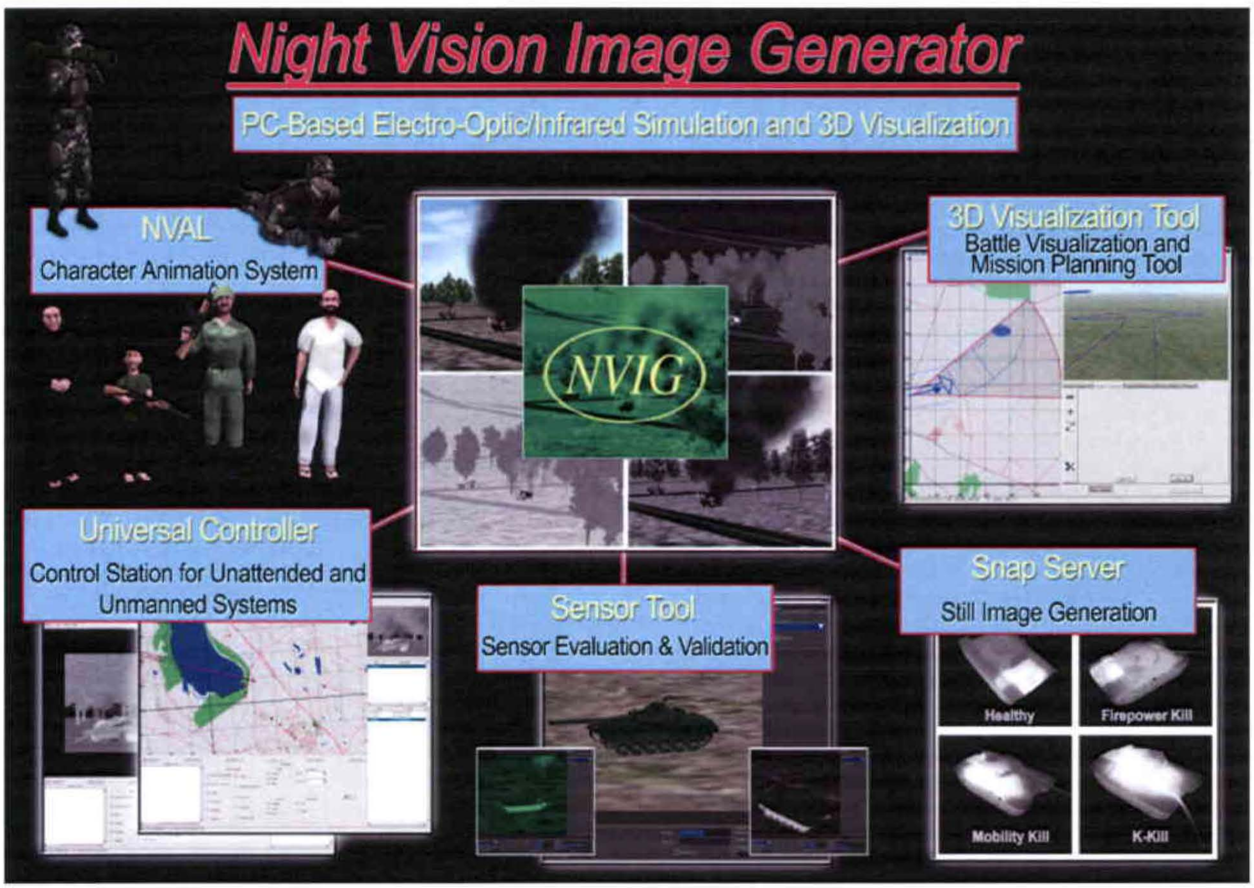

Figure 3. Night Vision Image Generator (NVIG)[5]

B. Vcom3D® Virtual Human Library

Vcom3D, Inc. is a commercial company that specializes in developing virtual human technology, including such capabilities as gestures, sign language, and facial expression[6]. This company provides an editor called Vcommunicator® Studio that allows a user to script activities for the human characters. Available options include adding the text for the character to speak, gestures to be performed, and expressions. Figure 4 shows a sample animation sequence inside the Vcommunicator Studio.

The Vcom3D Virtual Human Library shows a significant amount of potential due to the fact that it has been successfully integrated with such game engines as Gamebryo, Unity, and VBS2. Figure 5 shows some screenshots of the Vcom3D tools being used inside of these game engines, as well as the Forterra's OLIVE virtual world platform. However, while the library has been integrated with these renderers, there is not a packaged Software Development Kit (SDK) that would be easily used to add character animation to any rendering engine, although this could be accomplished with the assistance of Vcom3D, Inc.

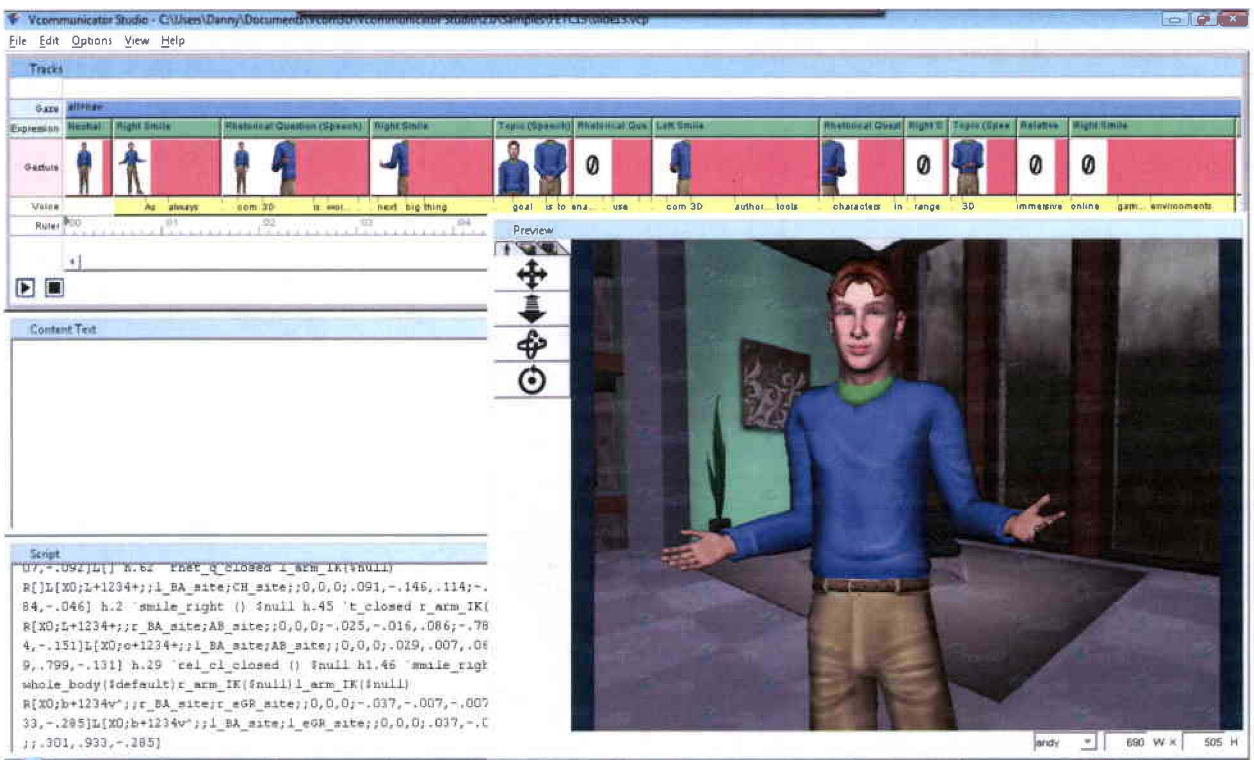

Figure 4. Vcommunicator Studio

Figure 5. Vcom3D's Virtual Human Library Integrated with Various Platforms[7]

C. Rocketbox Studios

Rocketbox Studios is a commercial company located in Germany. This company has developed three libraries of character models and animations in the Autodesk 3ds Max or Autodesk Maya formats. One library is called Complete Soldiers and contains 50 characters, along with 170 animations. The Complete Characters library contains 104 human character models of various types, along with 100 animations. Finally, the company provides the Complete Animals library, which contains 30 animal models with a total of 95 animations, including at least three for each animal. Each of the libraries provides models in 3 different polygon counts, which is necessary to allow for lower levels of detail when rendering large numbers of characters[8]. Figure 6 shows some of the models available through this set of libraries.

Figure 6. Rocketbox Studios Sample Models

The Rocketbox Studio models have been successfully integrated into the WorldViz Vizard™ 3D software toolkit[9]. Also, since the models are in a standard format and include animations, any software that is compatible with these formats should be able to import and use the library. Therefore, these libraries could be a good starting place for a custom software solution for character animation.

D. DI-Guy

DI-Guy is a commercial technology developed by Boston Dynamics, "an engineering company that specializes in building dynamic robots and software for human simulation"[10]. DI-Guy products include the DI-Guy SDK, DI-Guy Artificial Intelligence (AI), DI-Guy Scenario, and DI-Guy Motion Editor. While the company itself makes this claim, it is certainly apparent from researching the character animation options that DI-Guy is the de facto standard for human simulation in visual simulation community[11].

The DI-Guy SDK is accessible using C++ and includes a wide range of human characters, animals, and even vehicle models with articulated wheels and doors. In addition, the library includes thousands of motions for human behavior and also provides smooth transitions between these standard motions. The SDK is compatible with both Windows and Linux operating systems and has been integrated with numerous open source and proprietary rendering systems. Most importantly, DI-Guy has been integrated with the Rockwell Collins EPX IG. The capability provided in the EPX is accessible over the CIGI interface as described later. Figure 7 demonstrates various human characters interacting using DI-Guy.

Figure 7. DI-Guy Character Interaction[11]

The DI-Guy AI product provides crowd modeling and self-navigating capabilities, among other things. Large crowds can be quickly placed into a scene, and the individual characters have the ability to move independently about in a logical manner. Crowds can be controlled to perform tasks such as attacking vehicles or following an individual and also have the intelligence to avoid moving vehicles. It is also possible to control the types of characters in each crowd being added to a scene[12]. However, it should be noted that the latest DI-Guy crowd modeling capability is not currently available in the EPX IG system.

DI-Guy Scenario is a complete scenario generation system that allows a user to create actions for characters and vehicles within a Three-Dimensional (3D) environment. This tool can be used as a standalone training system or to generate scenarios that can later be replayed in a rendering system that uses the DI-Guy SDK.

DI-Guy Motion Editor, shown in Figure 8, is a tool that allows the user to create new motions for the DI-Guy characters. This includes the ability to read in the Bio-Vision Hierarchical (BVH) file format, allowing import of motion capture or animations from other software tools. Also, users can modify existing DI-Guy animations or even create completely new motions.

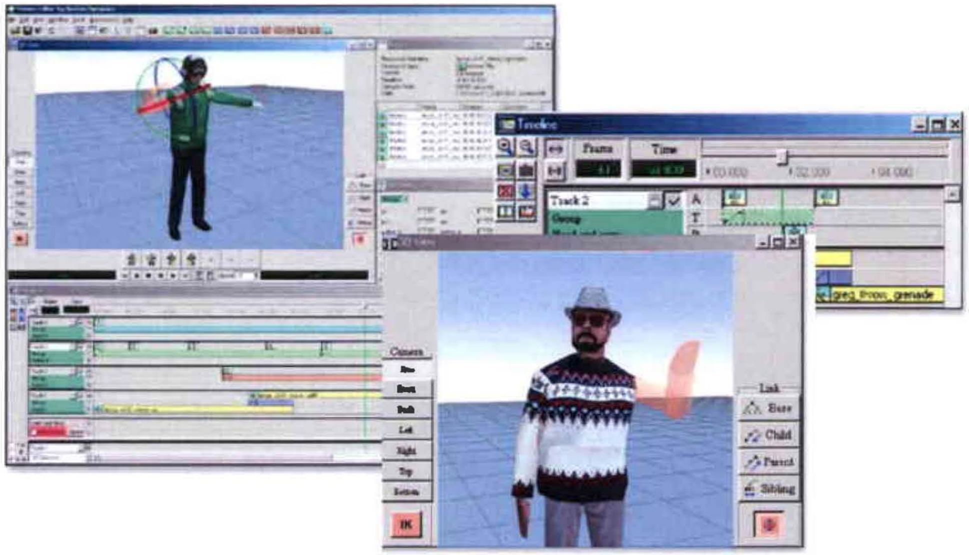

Figure 8. DI-Guy Motion Editor[13]

Interfacing a rendering engine to DI-Guy is accomplished using the DI-Guy C++ SDK. While not intended to provide a detailed description of using the SDK, sample code is provide in Figure 9 to demonstrate some of the interfaces. This code was taken from the DI-Guy SDK User's Guide and shows how to create a character and then set the position, orientation, and action for the character.

```
// initialize DI-Guy
diguy_ogl_initialize(NULL);

// Create a DI-Guy scenario
diguyScenario *scenario = diguy_create_scenario();

// Create a DI-Guy character of type soldier
diguyCharacter *character1 = scenario->create_character(
      "Character 1", // name
      "soldier7", // character type soldier
      NULL); // default parameters

// set the initial position, orientation, and action for the character
character1->set_position(0.0f, -3.0f, 0.0f);
character1->set_orientation(90.0f, 0.0f, 0.0f);
character1->force_action("kneel_ready");
```

Figure 9. DI-Guy SDK Sample Code[14]

As stated previously, the DI-Guy product is available for use with the EPX IG used on the CDT program. However, since it is a third party tool, there is an additional licensing fee required for activation. Once activated, the DI-Guy functionality is accessible via packets through the CIGI interface. CIGI packets each contain an opcode which identifies the packet type[15]. Rockwell Collins provides a document that shows specific opcode definitions related to DI-Guy. While this report is not intended to provide complete details on interfacing to DI-Guy,

Figure 10 does show an example of a CIGI packet that is used for aiming a DI-Guy weapon in the EPX IG.

Packet ID = 6	**EP Functionality**
Entity ID	Entity ID of the DI Guy
Articulated Part ID	241 (0xF1)
Flags	0 – Articulated Part Enable – Must be set to 1. 5 – Pitch Enabled 6 – Yaw Enabled
Pitch	Pitch angle in degrees
Yaw	Yaw angle in degrees

<table>
<tr><th>7 6 5 4 3 2 1 0</th><th>7 6 5 4 3 2 1 0</th><th>7 6 5 4 3 2 1 0</th><th>7 6 5 4 3 2 1 0</th></tr>
<tr><td>Packet ID = 6</td><td>Packet Size = 32</td><td colspan="2">Entity ID</td></tr>
<tr><td>Articulated Part ID = 241</td><td>Flags</td><td colspan="2">Reserved</td></tr>
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<tr><td colspan="4">Unused</td></tr>
<tr><td colspan="4">Unused</td></tr>
<tr><td colspan="4">Unused</td></tr>
<tr><td colspan="4">Pitch (32 bit packed float)</td></tr>
<tr><td colspan="4">Yaw (32 bit packed float)</td></tr>
</table>

Figure 10. DI-Guy Primary Weapon Aim CIGI Packet Used by EPX IG[16]

There is a significant cost associated with licensing this product, but the expected volume for CDT will allow for a lower runtime cost per system. Since DI-Guy is already available for use with the EPX IG, there is no development cost for integrating the technology with the IG. Therefore, with the significant capability provided by DI-Guy coupled with the fact that this technology is available on the EPX, it is clear that DI-Guy provides the quickest and easiest solution for improving the CDT's character animation.

E. MetaVR

While not an option for the current CDT project, the capability currently available in the MetaVR™ Virtual Reality Scene Generator™ (VRSG™) is worthy of mention as part of this analysis. The VRSG is "a Microsoft DirectX-based render engine that provides geospecific simulation as an IG with game quality graphics"[17]. While the VRSG provides integrated support for DI-Guy, it also provides custom character animation. Specifically, there is support for "hundreds of characters simultaneously within the field of view while maintaining a high frame rate"[18].

The VRSG comes with a library of over 200 character and weapon models, along with over 100 animations. The software computes smooth transitions between the animations. Figure 11 demonstrates the VRSG rendering a large crowd of people, while Figure 12 shows a military scene using VRSG characters.

Figure 11. Crowd Model in VRSG[15]

Figure 12. Military Scene in VRSG[15]

In addition to the numerous models already included in VRSG, it is also possible to create new models or modify existing models for VRSG using Blender, a free open source model creation tool[19]. Also, animations can be created and modified using Autodesk's MotionBuilder character animation software.

While it is understood that VRSG is not a viable option for integration with the EPX image generator, the capability represented helps to demonstrate the technology currently available. If the EPX requirement is removed in the future, options such as the VRSG would be made available to the CDT program.

F. Cal3D

Cal3D is an open source C++ character animation library that is platform-independent and graphics-rendering independent. The library provides a mechanism for inserting animated 3D characters into an application. In addition to basic animation playback capability, Cal3D also performs animation blending, which allows the developer to specify multiple animations on a single character at the same time while the Cal3D library smoothly blends the animations together. Cal3D also can automatically perform level-of-detail scaling to reduce polygon counts on characters based upon distance from the viewpoint. The operating systems supported by Cal3D include Windows, SGI Irix, Linux (various), and Mac OS X. Models can be created for Cal3D using 3D Studio Max. A tutorial for creating models of this type is available on the Cal3D website[20].

ReplicantBody is a character animation toolkit that can be used to integrate Cal3D capability into an application that uses the open source OpenSceneGraph rendering Application Programming Interface (API)[21]. AMRDEC currently uses a custom OpenSceneGraph-based library that uses ReplicantBody and Cal3D for character animation. Figure 13 below shows AMRDEC's Air Defense Artillery (ADA) Scenario Generator with a human character rendered in an OpenSceneGraph using ReplicantBody (and thus Cal3D). Figure 14 is a code sample that demonstrates how a ReplicantBody character can be assigned an animation.

Figure 13. AMRDEC Scenario Generator Showing Animated Human Character

```
bool spEntity::SetHumanAnimationState(std::string animation)
{
    // make sure animation string has ACT_ prefix
    if (!strstr(animation.c_str(), "ACT_")) {
        animation = "ACT_" + animation;
    }

    bool ret = false;

    vfw::EntityHuman *entHuman = dynamic_cast<vfw::EntityHuman*>
                (m_IsgEntity->GetVfwEntity());

    // verify entity exists
    assert(entHuman != NULL);

    rbody::OsgBodyNode *bodyNode = NULL;

    if ((entHuman != NULL) && (entHuman->GetNumBodyNodes() > 0)) {
        // use first body node
        const first = 0;
        bodyNode = entHuman->GetBodyNode(first);
    }

    if ((bodyNode != NULL) && (m_HumanAnimationString != animation)) {

        rbody::ActionRequest *action = NULL;

        action = bodyNode->getBody()->getActionPrototype(animation);

        if (action != NULL) {

            // create and execute animation action
            action->setPrioritized(false);
            bodyNode->getBody()->executeAction(action, false);

            // update current animation state
            m_HumanAnimationString = animation;

            // success
            ret = true;
        }
    }

    return ret;
}
```

Figure 14. AMRDEC Code Sample Showing Use of ReplicantBody

Based upon the success that AMRDEC has previously demonstrated using open source tools, including Cal3D, it is certainly feasible that a government-owned solution built upon open source technology could be created for the CDT program. However, with the current requirement to use the EPX IG, any long-term saving by using government-owned software would be negated by the upfront cost of developing the technology and integrating it into the IG.

Also, while individual characters could be animated easily enough using the current technology, advanced features such as crowd modeling would require additional research and development. Therefore, this technology does not appear to be a viable alternative for the current requirement, although it should be reconsidered when the EPX IG requirement goes away.

V. RECOMMENDATION

While there are several directions that the CDT could pursue long-term, it is evident that the most cost and schedule effective near-term solution is for the CDT program to use DI-Guy. The CDT program currently has a requirement to use one specific IG, the Rockwell Collins EPX. This requirement limits the options available for character animation to that which is currently supported by the IG or requires the vendor to make changes to the IG directly. The only good option currently integrated with the EPX IG is DI-Guy. Considering the likely cost of changing the IG, along with the fact that the DI-Guy solution will meet the most critical near-term requirements, AMRDEC recommends that the CDT program obtain the necessary licenses to DI-Guy for integration with the trainer. However, in the long-term, it is recommended that the CDT program remove the requirement for a specific IG, allowing other commercial, open source, or government-owned rendering capabilities to be considered. This would give the program much more flexibility and potentially lead to technical improvements and even cost savings.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAR	After Action Review
AI	Artificial Intelligence
AMRDEC	Aviation and Missile Research, Development, and Engineering Center
API	Application Programming Interface
BVH	Bio-Vision Hierarchical
CDT	Common Driver Trainer
CERDEC	Communications-Electronics Research, Development, and Engineering Center
CIGI	Common Image Generator Interface
COTS	Commercial Off-The-Shelf
IG	Image Generator
IOS	Instructor/Operator Station
MRAP	Mine Resistant Ambush Protected
NVAL	Night Vision Animation Library
NVIG	Night Vision Image Generator
PC	Personal Computer
PEO STRI	Program Executive Office for Simulation, Training, and Instrumentation
RDECOM	U.S. Army Research, Development, and Engineering Command
SDK	Software Development Kit
VRSG™	Virtual Reality Scene Generator™

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